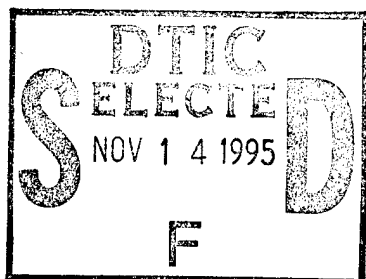


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OF POSITION LOCATION IN MOBILE C³I SYSTEM

by

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IMPLEMENTATION METHOD AND ACCURACY ANALYSIS OF
POSITION LOCATION IN MOBILE C³I SYSTEM

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ABSTRACT: This paper mainly discusses the implementation method of node-position location in the TDMA communication mode in a mobile C³I system and some factors affecting the accuracy of position location and their methods of correction.

KEY WORDS: Radio location, time-of-arrival location method, mobile communications, time-division-multiple-access, relay station, C³I system.

I. Introduction

Mobile communication subsystems are an important integral part of command, control, communications, and intelligence systems. However, a communications system directly affects communication efficiency. The communication mode time-division-multiple-access (TDMA) can share a transmitter by multiple communication channels with one frequency and one antenna without requiring large and easily worn-out shared control devices for

the antenna, besides having good features of antijamming techniques such as frequency expansion and frequency jumping. Therefore, TDMA is preferred by military communications operators. Thus, in field combat C³I mobile communications, the TDMA mode is the most suitable regime of military communications.

The mobile C³I system operating with TDMA broadcasting mode is a mobile communication system without a center. There are different numbers and levels of the system members. More time gaps are distributed for those users with high traffic and high grades. Each user in the system has a highly accurate quartz clock, and the entire system has one unified time datum. Through timing with or without a source for each user, a user can actively synchronize with the system time datum so as to establish a unified system time. This is a precise synchronizing system.

System users include the main control station, users for navigation guidance control, position datum users, and other kinds of users.

There is a relatively long history of positioning by using broadcast radio waves. However, the high-accuracy positioning technology is used in modern military practice. This can be carried out only through today's developments in science and technology. In mobile C³I, the positioning technique to position system members is advantageous in enhancing the discriminatory capability between friend of foe by system members, thus

preventing friendly-fire casualties, and upgrading combativeness and survivability of system members. In a mobile C³I system, the TDMA communication mode is basic. By using the time-of-arrival (TOA) surveying technique to position the system members, not only is there the comprehensive positioning capability combined with data transmission, but also one can automatically track the positions of user elements, thus greatly reducing the risk of accidents attacking friendly surface troops.

In the TDMA communication mode, the article discusses the principles of positioning multiple nodal points in the system by using the TOA surveying technique, as well as several major factors and revision methods affecting the positioning accuracy of the nodal points.

II. Implementation Method for the Principle of Positioning Nodal Points with the Mobile C³I System

II.1. TDMA operating principle

We know that in order to operate digital communications, we must first implement network synchronization of the digital communication network. In the TDMA communication network, synchronizing is also necessary. Fig. 1 shows the classification of the TDMA signal frame structure. By citing an example, the Joint Tactical Information Distribution System (JTIDS) of the United States Armed Forces, in JTIDS TDMA periodically divides the time axis into a time element with duration of 12.8min. One time element is divided into 64 time frames, which is 12s for each frame. Each time frame is divided into 1536 time slots

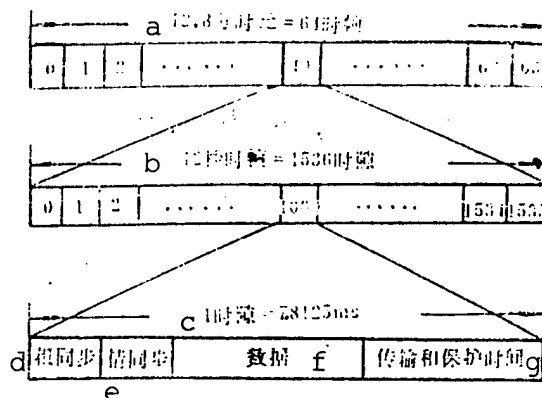


Fig. 1. Schematic diagram for frame configuration of TDMA signal.

KEY: a - 12.8min of time element = 64 time frames
 b - 12s time frame equals 1536 time slots c - one time slot equals 7.8125ms d - phase synchronization
 e - accurate synchronization f - data g - transmission and guard time

each time slot is 7.8125ms long. Therefore, each time element includes 98,304 time slots. A time slot is composed of a synchronizing segment, a data segment, and a transmission and guard segment.

With the classifying of time slots in each time element a certain number of time slots is distributed to each system member in which signals are to be transmitted; however, in the time not transmitting signals, the member receives signals transmitted by other members. Each system member has an accurate time clock. In the entire system, synchronizing is realized with the specified network synchronizing time slots so that the entire system network is established on a unified time datum, thus forming a unified system time. There are two functions for the system time: (1) all members have a unified standard on

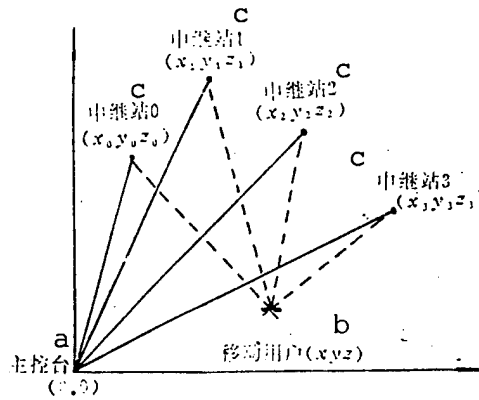


Fig. 2. Principle of geometric structure of nodal-point positioning
a - main control station b - mobile user
c - relay station

classifying time element, time frame and time slot, so that each transmission has a timing datum at the unified beginning point of the time slot, thus TDMA can operate normally. (2) As the beginning point in TOA surveying, as the surveying standard, a fundamental positioning navigation guidance for the nodal points is realized.

II.2. Nodal point positioning principle in TOA surveying.

In a mobile C³I system, after precise synchronization is carried out among the entire system members, and between the main control station and the navigation guidance control users, it is required that a positioning request is issued by the mobile users with positioning requirement within the specified time slot. The higher-grade elements, having been precisely positioned, are the relay stations, which transmit received signals to the main control station. Through several relay stations involved in

surveying, the main control station relays the TOA signal, thus determining the positions of mobile users who request positioning.

In order to accomplish overall three-dimensional positioning, at least four relay stations are required, as shown in the figure. Thus, the following set of equations can be derived.

$$\begin{aligned} & (x-x_i)^2 + (y-y_i)^2 + (z-z_i)^2 \\ & = (D_0 + d_i)^2 \quad i=0, 1, 2, 3 \\ & d_0 = 0 \end{aligned} \tag{1}$$

In the equation (x, y, z) are the coordinates of the mobile user positions; $(x_i, y_i, z_i) i=0, 1, 2, 3$ are the coordinates of the relay stations; D_0 is the distance between the mobile user and relay station 0; D_i is the distance between the mobile user and the i -th relay station; $i=0, 1, 2, 3$.

d_i is the difference between the distance from the mobile user to relay station 0, and the distance between the mobile user and the i -th relay station, that is, $d_i = D_0 - D_i$, $i=0, 1, 2, 3$.

R_0 is the distance between the main station and relay station 0.

R_i is the distance between the main control station and the i -th relay station; $i=1, 2, 3$.

r_i is the difference between the distance R_0 between the main control station and relay station 0, and the distance R_i between the main control station and the i -th relay station. That is, $r_i = R_i - R_0$, $i=1, 2, 3$.

TOA_i is the time of arrival for signals reaching the main control station by the i -th relay station transmitted to a mobile user, $i=0, 1, 2, 3$.

$DTOA_i$ is the difference between TOA_0 and TOA_i ($i=1, 2, 3$).

C is speed of light.

Then,

$$r_i = R_i - R_0 \quad (i=1, 2, 3) \quad (2)$$

$$DTOA_i = TOA_0 - TOA_i \quad (i=1, 2, 3) \quad (3)$$

$$d_i = C \times DTOA_i - r_i \quad (4)$$

Here, since (x_i, y_i, z_i) , $i=0, 1, 2, 3$ are known. By computing R_i , we can obtain r_i . If TOA_i is determined, by using Eq. (4) we can obtain d_i . Thus, we can obtain the position coordinates (x, y, z) of the mobile user and D_0 by using Eq. (1).

The following explanations are applicable.

(1) There are four unknowns in Eq. (1). Since this is a nonlinear equation, multiple roots and imaginary roots may be generated. One of the methods for eliminating extra roots is as follows. If the altitude z of the position coordinates of various relay stations and the mobile user can be determined or estimated by other methods, then the horizontal coordinates x and y can be determined by using only three relay stations and three TOA . This method is helpful in reducing the number of multiple roots or imaginary roots. Another method is the utilization of outside signals to determine and to eliminate the roots thus obtained, such as determination that involves map data and other signals previously stored in computers of the main control station.

(2) TOA surveying is the key to solving the equations. The accuracy of TOA surveying directly affects the accuracy of position coordinates. Therefore, the TOA surveying technique is the key. Some measures can be adopted to enhance the accuracy of TOA surveying, such as using frequency expansion for ranging, highly-precise quartz oscillations, timely correction of the time datum, and eliminating transmission and computational errors. However, DTOA is one of the measures for eliminating the broadcast errors. In the following, we will discuss several factors affecting positioning accuracy and the revision method.

III. Analysis of Positioning Accuracy of Nodal Points

In the above mentioned positioning process, positional accuracy is determined mainly by the following error sources.

These include positional quality of datum source, and time control of the main control station; synchronizing accuracy of network members; and relative geometric relationship between mobile users and navigation guidance control users who act as relay stations; TOA surveying accuracy; and computational errors of computers.

III.1. The effect on positioning accuracy of nodal points due to positional quality and time quality.

In a C³I system in modern warfare, a system member not only should precisely know his relative position to the main control station, but sometimes it is also required to precisely know his

geographical coordinates. Ordinary users are unable to install such expensive geodetic systems, relying only on the main control station. In the discussion made in the preceding sections, a mobile user can determine his relative position from the main control station. If the main control station ascertains a geographic coordinate point as the geographic coordinate source of the system, and provides the information to other users, then when necessary a mobile user can compute his geographic coordinates. Hence, the absolute positioning accuracy of the mobile user relies on the coordinate accuracy of the datum source. By using highly-precise geodetic survey data, such as a geodetic vehicle, or a global positioning system (GPS receiver, a difference GPS receiver, to provide real time all-weather precise geographic coordinates. At the same time, the time quality of the main control station sets a limit on the positional accuracy of mobile users. Generally speaking, to satisfy system requirements, the main control has to use highly-stable, highly-accurate clocks, such as an atomic clock or a satellite clock, among others.

III.2. The effect of nodal points on positional accuracy by synchronizing accuracy.

In the foregoing we mentioned that TDMA is the basis of positioning for system nodal points; however, the TDMA network should be a synchronizing network. Hence, the synchronizing accuracy of a network member also directly affects the

positioning accuracy of system members. We know that when a network non-member intends to join the system network, first the network entering signal from the main control station should be waited for. After receiving the network entering signal, accuracy synchronization is then made with the system network. In the following, we analyze in detail the error generated by synchronization of network members. Generally, a member entering the network adopts the source timing to accomplish the timing with system time datum.

As shown in Fig. 3, when the network-entering signal from the main control station is received by user B who requested synchronization, after crude synchronization is accomplished, within the ranging time slot, user B issues the application signal for ranging to user A, who has achieved synchronization. User A determines the arrival time t_1 of user B's signal, and the time t_2 for transmitting the response signal. Together with the response signals, these two data are transmitted to user B. Based on his time datum surveying signal, and the time T from the transmission to the receiving of the response signal, based on the following equation, user B can solve for the error Δt of the time datum.

$$\Delta t = (t_1 + t_2 - T) / 2 \quad (5)$$

Of course, this is in the situation that a system member is immobile; this can be accomplished with a single timing. When system members are in an immobile state, in the situation of approaching motion, the transmission time delay of the ranging response is less than the transmission time response of ranging

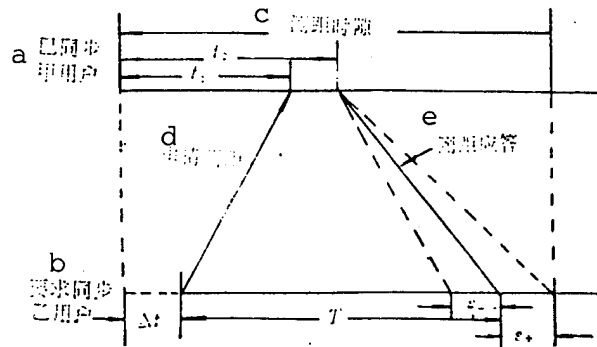


Fig. 3. Difference timing error due to different directions of motion
 ϵ_+ is the error due to backing-away motion
 ϵ_- is error due to approaching motion
 KEY: a - synchronized user A b - synchronization request of user B c - ranging time-slot
 d - ranging request e - ranging response

application. From Eq. (5), we can obtain the error Δt of the time datum:

$$\begin{aligned}\Delta t &= [t_1 + t_2 - (T - \epsilon_-)]/2 \\ &= (t_1 + t_2 - T)/2 + \epsilon_-/2\end{aligned}\quad (6)$$

In the situation of backing-away motion, the transmission time delay in ranging response is greater than the transmission time delay in ranging request. From Eq. (5), we can obtain the error Δt of the time datum:

$$\begin{aligned}\Delta t &= [t_1 + t_2 - (T + \epsilon_+)]/2 \\ &= (t_1 + t_2 - T)/2 - \epsilon_+/2\end{aligned}\quad (7)$$

From Eqs. (6) and (7), we can see that in the situation of approaching motion, the approaching motion increases the measurement value $\epsilon_-/2$. If this time datum error of measurement

is used to adjust the user's time datum, then the error $\epsilon_-/2$ is the result. In other words, user's time datum is advanced from the time datum of the system standard source by the period $\epsilon_-/2$. Conversely, in the situation of backing-away motion, the backing-away motion reduces the time datum error by an amount $-\epsilon_+/2$. If the time datum error measured at that time is based on adjusting user's time datum, then the error $-\epsilon_+/2$ is produced. In other words, the user's time datum lags behind the time datum of the system standard source by a period $-\epsilon_+/2$. Thus we can see that the relative motion of system members is one of the errors of system time correction thus generated.

From Fig. 3 and the analysis in Eqs. (6) and (7), we also know that the longer the time delay t_2 of ranging response, the larger is the error of $\epsilon_-/2$ or $(-\epsilon_+/2)$ generated by the relative motion among system members. We can see that when the time of ranging response is greater than the time of ranging request, this is also one of the errors of system time correction thus generated.

III.3. Positioning error due to geometric relationships between the mobile user and the user who acts as a relay station.

From geometry, we know that the relative geometric relationship between the user, and the user acting as a relay station will generate the effect of geometric dilution of accuracy (GDOP), which is known by many. GDOP is defined as the summation t_{RMS} of the RMS for the diametral positional error and

the linear RMS of positional error, that is, the ratio of Δ_r . In other words,

$$d_{\text{RMS}} = \text{GDOP} \times \delta,$$

Generally speaking, in selecting a relay station the following is very important. Only those relay stations with good geometric relationships with users can be considered for use in positioning computations. If the angular difference between various sources observed from user position is about 90° , then the error is minimum that is generated by geometric relationships. Conversely, if the angular difference approaches 0 or 180° , then the error generated is the maximum.

III.4. The effect on positioning accuracy of nodal points by measuring accuracy of TOA.

The measurement accuracy of TOA is related to the following factors: bandwidth of user receiver; signal-to-noise ratio of the signal; frequency stability of clock; error in measurement electrical circuits; propagation error of radio waves; and speed of response signal by the datum source.

The transition time of a signal in a user receiver increases with decrease in bandwidth. Because of variation of aging or environmental conditions, this transient time will vary. Obviously, the narrower the frequency band of a receiver, the greater is the variation of transition time. The signal synchronization head generates timing datum pulse in the receiver. Due to noise, the timing pulse will flutter. The specific fluttering range is closely related to the signal-

to-noise ratio. However, the short term frequency stability of a clock is obvious in the accuracy effect of positioning. The propagation anomaly and multichamber reflections of radio waves in the atmosphere will affect the TOA measurement accuracy. The effect on TOA measurement by multichannel reflection is determined by amplitude and phase (these are the area and position of the reflector) of the reflection wave. The error in TOA measurement can be estimated by using the following formula.

$$\Delta t = \Delta T \cdot \rho / (1 + \rho) \quad (8)$$

In the equation, Δt is the TOA measurement error due to multichannel interference; ΔT is the delay of a direct wave by a reflected signal; and ρ is the energy ratio between the reflected signal and the direct wave.

We can see that the more intense the reflected wave, the longer is the time delay and the greater the effect.

Generally speaking, the higher the speed of response information from various sources, the higher is the positional accuracy of users. The better performance of the measurement circuit, the smaller is the measurement error that can be induced. Based on the developmental levels of modern computer technology, the computational error can be so small that it can be neglected.

IV. Conclusions

The article discusses mainly the positioning technique of a system member requesting a mobile C³I system. Application of

this technique is significant to the combativeness and survivability of the system as well as the enhancement of friend-or-foe discrimination of the system. The basis for achieving this technique is the TDMA communication mode, and the key technique is the TOA measurement technique. There is still a technical blank in China in nodal point positioning that involves using the TOA measurement technique in C³I systems. From the previous analysis, we know that there are the following factors affecting the positioning accuracy: the positional quality of the source and the time quality of the main control station, synchronizing accuracy of a network member, the GDOP coefficient and computational errors between relay station and user. However, other than the relationship between TOA measurements and the corresponding measurement circuit performance, also closely related are signal bandwidth, signal-to-noise ratio, and propagation environment.

The author is a 27-year-old male holding the rank of assistant engineer. In 1989, he graduated from the Xi'an University of Electronics, Science and Technology. The article was received for publication on February 8, 1993.

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